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Characterization of Natural Resources in the Narmada Canal Project Area of Rajasthan for their Management under Canal Command Irrigation

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Abstract: The Narmada Canal Project (NCP), in the southwestern parts of arid Rajasthan, caters to the irrigation needs of 0.246 mha area in drought-prone districts of Jalore and Barmer in Rajasthan. A systematic investigation was undertaken to assess the state of natural resources i.e. soils, landform, and water in response to continuous canal irrigation in the Narmada Canal Project area in two arid districts of arid Rajasthan. Soils in the NCP area in Rajasthan were found very deep, slightly to strongly alkaline in reaction (pH 7.62 to 9.98), sandy to silty loam in texture at surface and loamy sand to sandy loam in texture at the subsurface. Five soil series were characterized and mapped in the course of the investigation. Four soil series belonged to the aeolian plains covering 74% area of NCP and these are Sanchore, Dhorimana, Chohtan and Dune complex whereas one soil series i.e. Chitalwana was identified belonging to alluvial plains covering 10% area of NCP. Organic carbon content ranged from 0.03 to 0.42% in the surface soils with a decreasing trend along the depth. Available N, P and K content in surface soils ranged from 61.9 to 191.0 kg ha^{-1}, 1.41 to 47.84 kg ha^{-1} and 56.25 to 652.50 kg ha^{-1}, respectively. Similarly, Fe, Mn, Zn and Cu ranged from 0.85 to 13.46 mg kg^{-1}, 1.72 to 14.55 mg kg^{-1}, 0.08 to 2.40 mg kg^{-1} and 0.02 to 1.38 mg kg^{-1}, respectively. Based on visual interpretation of satellite images and subsequent ground truthing, ten types of landforms have been characterized in the area, which have been categorised under fluvial, aeolian and coastal kinds. Among the landforms of fluvial origin, alluvial plains occur in about 37% of total area under NCP and have been further mapped as younger and older alluvial plain types. Analysis of groundwater in the NCP area of Rajasthan revealed medium sodicity of groundwater with the value of sodium adsorption ratio ranging from 0.15 to 36.31. The residual sodium carbonate of groundwater ranged from almost nil to 5.7 me L^{-1} with a mean value of 1.1 me L^{-1}. Among the cations and anions, Na^+ and Cl^- are the dominant ions and their concentrations ranged from 0.27 to 95.50 me L^{-1} and 1.40 to 92.40 me L^{-1}, respectively. Benchmark characterization of these soil and water resources will help in future assessment

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and best management of natural resources specifically in canal command area located in arid landscape.

The arid region of India has limited natural resources in comparison to other parts of the country. Agriculture in the region primarily relies on monsoon rains, with only a limited dependence on well and tube well irrigation, which are found in scattered pockets throughout the area. The major developments in irrigation facility in the region started in the late 1960s with the introduction of Indira Gandhi Nahar Pariyojana (IGNP) and later in 2008 with the introduction of the Narmada Canal Project (NCP). A vast area of arid Rajasthan has been brought under canal irrigation to overcome the recurrent occurrence of droughts, to reduce the severity of erosion and to increase biological productivity of the region. At present, about 62.6% of the net irrigated area in arid Rajasthan is irrigated through wells and tube wells whereas 37.2% is irrigated through the canals i.e. IGNP and NCP (Rajasthan Agricultural Statistics, 2021-22). The situation demands careful management of land resources based on precise scientific information on its characteristics, potentials, and limitations. Detailed information on the state of natural resources is of paramount importance for their sustainable and rational utilization to ensure food, nutrition, and fodder security. Natural resources information also provides a sound basis for the transfer of technologies in agriculture. The data on natural resources viz., landform, soil, water, land use and land degradation may be utilized as decision support aids for formulating development plans.

Soil resource characterization provides information for understanding the physico chemical properties of soils which are highly important and suitable for crop production, forests, grasslands, and for home and society (Devi *et al.*, 2015). The scientific inventory of soil resources of the region provides predictions about behaviour of defined kinds of soils under stated conditions and expected results of interpretation between soil characteristics, crop requirement, and management practices. The soils of hot arid regions of Rajasthan are usually deficient in several major and micro-nutrients, and there is large spatial variability in the plant-available nutrient content of the soils (Gupta *et al.*, 2000; Praveen-Kumar *et al.*, 2009; Mahesh Kumar *et al.*, 2021). This calls for comprehensive knowledge of soil resources in terms of types of soils, their spatial extent, physical and chemical properties, and limitations or capabilities.

Rainfall is the major source of water in arid regions. Surface water resources are limited due to low and scanty rainfall and poor water yielding efficiency of sandy terrain. The total surface water resources of arid zone of Rajasthan, excluding Indira Gandhi Nahar Pariyojna (IGNP), is 1361 million cubic meters (MCM). The underground water reserve of the region is 4545 MCM, with 4282 MCM being utilized for irrigation. An analysis of the stage of groundwater development under cropped and irrigated area indicated that the groundwater development has exceeded 100% in six districts of western Rajasthan (Moharana *et al.*, 2016). Overexploitation of groundwater poses serious threats to the sustainability of agriculture in the region. In Rajasthan, approximately 80% of the groundwater has an electrical conductivity (EC) greater than 2.2 dS m^{-1}, and most of the water used for irrigation exhibits an EC exceeding 5 dS m^{-1}. The continuous use of this saline groundwater contributes to the increasing soil salinity in the region. The canal irrigation in hot arid regions triggered considerable development of agriculture which resulted in an increase in crop productivity manifolds, but it also brought problems of water logging and secondary salinization in some areas because of lack of proper drainage, excessive irrigation and seepage from the canals.

During 2008-09 the Narmada Canal Project was introduced in the southwestern parts of the thar desert, which provides irrigation to 0.246 mha area of cultivable fields in some parts of Jalore and Barmer districts. Farmers in the districts have started realizing benefits of the canal irrigation since 2008. After running through the long 458 km distance from Sardar Sarovar dam in Gujarat, the Narmada canal enters into Rajasthan near Shilu village in Jalore district. The Narmada main canal is 74 km long in Rajasthan with a distribution system of 1719 km comprised of distributaries, sub distributaries and minors. Pressurized irrigation is made mandatory in the entire command area with certain innovative features. Sporadic information is available on land resources of the arid Rajasthan but very limited information is available, especially on the state of natural resources in the NCP area of Rajasthan. Hence the present study was undertaken to characterize and benchmarking of sites in NCP area of Rajasthan to assess the state of natural resources in response to continuous irrigation and for continuous monitoring of the same.

Materials and Methods

Study site

The Narmada canal project of Rajasthan is located between 24°37′ to 25°18′N and 71°3′ to 71°52′E covering Jalore (Sanchore and Chitalwana tehsils) and Barmer districts (Gudamalani tehsil) of Rajasthan in India with a command area of 0.246 mha area (Fig. 1). It encompasses vast stretches of sandy flats, undulating sandy plains (dune height of 5 to 20 m) and alluvial plains on an altitude of 213 to 400 m above mean sea level. It is bordered by the Banaskantha district of adjoining Gujarat state in the south and is surrounded by Rajasthan districts on the other three sides: Sirohi to the southeast, Pali to the northeast, and Jodhpur to the north. The command area has three physiographic units viz. alluvial plains, aeolian plains and duny complex.

The climate of the NCP area is arid and has an average annual rainfall of 380 mm of which >80% occurs from June to September, extremes of temperature (maximum and minimum temperatures in the study area recorded are 48.9°C and -1.7°C), high evapotranspiration, frequent droughts and wind speed during summer with dust storms. Pearl millet (*Pennisetum glaucum*), clusterbean (*Cyamopsis tetragonoloba*), mung bean (*Vigna radiata*) and sesamum (*Sesamum indicum*) with occasional castor (*Ricinus communis* L.) are the major kharif crops grown in both the districts. Whereas, cumin (*Cuminum cyminum*), isabgol (*Plantago ovata*) mustard (*Brassica* sp.) and wheat (*Triticum* sp.), are grown with irrigation from canal water in the rabi season.

The Narmada canal in the arid parts of Rajasthan receives water from Narmada River, which originates from the Amarkantak in the Shahdol district of Madhya Pradesh. Which enters the arid Rajasthan after covering a great distance (≈1300 km) in Madhya Pradesh, Maharashtra and Gujarat states. The length of main Narmada canal in Rajasthan is 74 km with 12 main distributaries including four lift distributaries and taking off from the main canal. The total length of the distribution system comprising of distributaries, minors, sub-minors is about 1719 km. The Narmad canal was designed to provide irrigation and drinking water to the Jalore and Barmer districts of Rajasthan located in southwest of Thar Desert, Rajasthan. For efficient utilization and ensured optimized regulation of canal water, pressurized irrigation with drip and

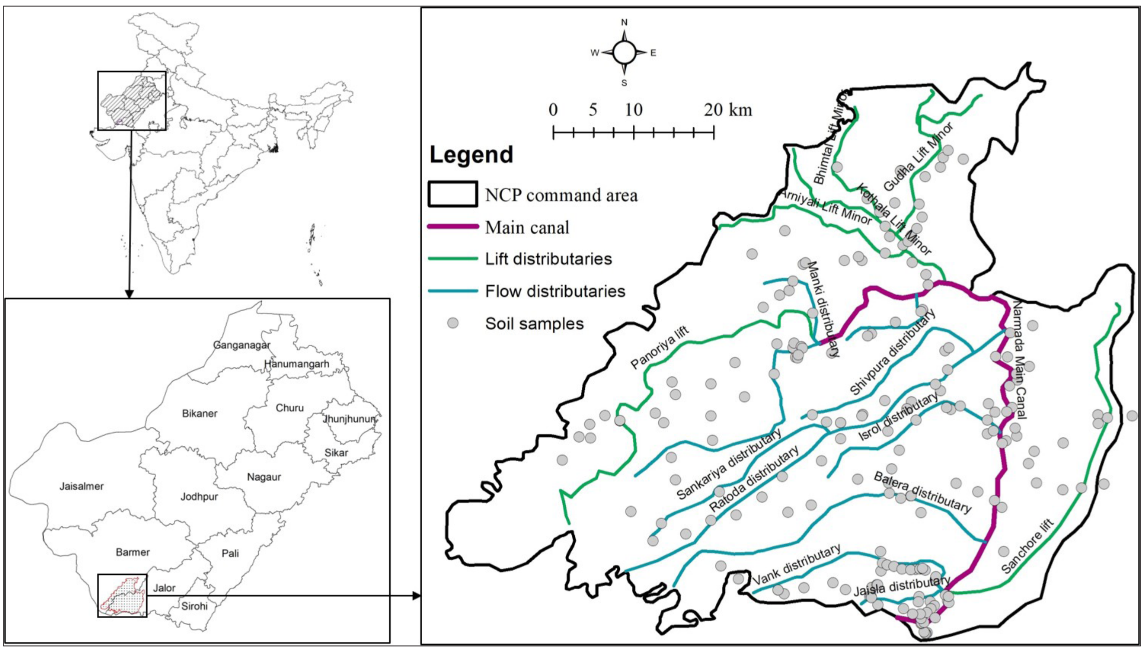

Fig. 1. Location of the study area.

sprinklers has been made mandatory in the command area. The water from main canal/distributaries is drawn into diggies (shallow surface water reservoir) and water from diggies is carried through buried HDPE pipes and farmers are drawing their shares by using their sprinkler and drip sets at the outlets provided. The command area of Narmada canal is broadly grouped in to three categories based on method of irrigation (lift or gravity flow) (i) normal flow area (ii) lift area and (iii) ned area.

Soil sampling and laboratory analysis

Soil survey has been carried out on 1:50,000 scale following interpretation of satellite images e.g. IRS LISS III; field survey and laboratory characterization of collected soil samples; and mapping of resources through geographical information system (GIS). During the field survey, detailed morphological studies of soil profiles were carried out (Soil Survey Staff, 2014), and horizon-wise soil samples were collected for detailed laboratory characterization. Locations of the sampling places were recorded with the help of global positioning system (GPS). Besides these, soil profiles were also examined during the field traverse for correlating the soils for the preparation of soil map of NCP, Rajasthan. Collected soil samples were pre-processed by air drying and passing through 2 mm sieve followed by laboratory analysis to determine soil properties (Page *et al.,* 1982). Soil reaction or pH was determined by pH meter using soil: water suspensions prepared in a 1:2 ratio. Soil electrical conductivity (EC) was determined using conductivity bridge (Jackson, 1973). Organic carbon content and $CaCO_3$ content in soils were estimated following the methods proposed by Walkley and Black (1934) and Piper (1966). Available phosphorus (P) was extracted with 0.5M $NaHCO_3$ solution (8.5 pH) and phosphorus in the extract was estimated using spectrophotometer (Olsen *et al.,*1954). Available potassium (K) was determined by extraction of soil with neutral normal ammonium acetate (pH 7.0 in 1:5, soil: solution ratio) followed by estimation of the content with the help of flame photometer (Pratt, 1982). Available iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) in the soil were extracted with DTPA reagent (Lindsay and Norvell, 1978) and were determined with the help of Atomic Absorption Spectrophotometer (GBC-932A). Soil textural analysis was carried out by the international pipette method (Piper, 1966) using sodium hexametaphosphate as a dispersing agent. The textural class was determined using the USDA textural triangle.

Groundwater characterization and laboratory analysis

To characterize the underground water quality in the NCP area and to assess its suitability for irrigation, 46 geo-referenced underground water samples were collected. These water samples were analysed using standard methods and interpreted by using different indices for salinity-sodicity and suitability for irrigation. Water samples were analysed for cations and anions using the standard method (Richards, 1954). The Ca^{2+} and Mg^{2+} were analysed through versenate titration method, Na and K by flame photometer and Cl^-, $SO_4{}^{2-}$, $CO_3{}^{2-}$, $HCO_3{}^-$ by standard titration methods. The sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were calculated as follows:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}} \quad ...1$$

$$RSC = (CO_3^{-2} + HCO_3^-) - (Ca^{+2} + Mg^{+2}) \quad ...2$$

where, Na^+, Ca^{+2}, Mg^{+2}, are ionic concentration of sodium, calcium, magnesium, carbonate and bicarbonate, respectively in meq L^{-1}. SAR is generally used to estimate the potential of Na^+ to accumulate in the soil primarily at the expense of Ca^{2+} and Mg^{2+} because of the regular use of sodic water (Bhat *et al.*, 2018). Richard (1954) has classified the quality of water on the basis of sodium absorption ratio (SAR). SAR is an important parameter for the determination of soil alkalinity or alkali hazards in the use of groundwater for agricultural applications (Srivastva and Ramanathan, 2008). RSC is generally used to assess the hazardous effect of carbonate and bicarbonates on irrigation water quality (Srivastva and Ramanathan, 2008).

Results and Discussion

Morphological and physicochemical characterization of soils

Classification and extent: Soils of the NCP area in Jalore and Barmer are yellowish brown (10 YR 5/4) to dark yellowish brown (10 YR 4/4)

Table 1 Morphological characteristic of soil series of Narmada canal project of Rajasthan

Horizon	Depth (cm)	Color	Texture*	Structure**	Consistence#			Boundary##
					dry	moist	wet	
Sanchore series: Typic Torripsamments								
AP	0-20	10YR6/3	fs	sg	l	l	s0/p0	
C1	20-60	10YR5/4	fs	sg	l	l	s0/p0	cs
C2	60-90	10YR5/3	ls	sg	l	l	s0/p0	ds
C3	90-150	10YR5/3	ls	sg	l	l	s0/p0	ds
Dhorimana series: Typic Torripsamments								
AP	0-20	10YR6/4	fs	sg	l	l	s0/p0	
C1	20-50	10YR5/4	fs	sg	l	l	s0/p0	cs
C2	50-120	10YR5/4	fs	sg	l	l	s0/p0	ds
C3	120-160	10YR6/4	fs	sg	l	l	s0/p0	ds
Chauhtan series: Typic Torripsamments								
AP	0-35	10YR6/3	fs	sg	l	l	s0/p0	
C1	35-75	10YR5/4	fs	sg	l	l	s0/p0	cs
C2	75-130	10YR5/4	fs	sg	l	l	s0/p0	ds
C3	130-150	10YR6/4	ls	sg	l	l	s0/p0	ds
Chitalwana series: Typic Torrifluents								
AP	0-20	10YR5/3	sil	f 1 sbk	sh	fr	ss/sp	
C1	20-65	10YR5/3	sil	f 1 sbk	sh	fr	ss/sp	cs
C2	60-95	10YR5/3	sil	f 1 sbk	sh	fr	ss/sp	cs
C3	95-120	10YR5/4	sl	f 1 sbk	sh	fr	s0/p0	as
C4	120-150	10YR5/4	ls	f 1 sbk	sh	fr	s0/p0	as
Dune Complex series: Typic Torripsamments								
AP	0-25	10YR6/3	fs	sg	l	l	s0/p0	
C1	25-75	10YR6/4	fs	sg	l	l	s0/p0	ds
C2	75-130	10YR6/4	fs	sg	l	l	s0/p0	ds
C3	130-150	10YR6/4	fs	sg	l	l	s0/p0	ds
C4	130-180	10YR6/4	fs	sg	l	l	s0/p0	ds

*ls-loamy sand;fs-fine sand;sil-silt loam;l-loam;sl-sandy loam;gsl-gravelly sandy loam ** sg-single grained; f-fine, m-medium, 1-weak,2-moderate,sbk-subangular blocky; # l-loose, sh-slightly hard, fr-friable;s0-none slight;ss-slightly sticky,p0-none plastic, sp- slightly plastic ## cs-clear smooth, ds-diffuse smooth, as –abrupt smooth, gs-gradual smooth, aw–abrupt wavy.

in color. Value and chroma ranged from 4 to 5 and 4 to 6, respectively in the surface soils of Sanchore, Dhorimana, Chauhtan and Dune complex series, however, subsoil exhibited dominantly one-unit darker chroma, whereas, the Hue was 10 YR. It was primarily attributed to comparatively higher silt and clay content *vis-à-vis* higher moisture retention for longer duration (Table 1). Hummocky phase of Sanchore and Dune complex series showed similar color characteristics (10 YR 6/4 to 10 YR 5/4) at the surface because of common source of aeolian sand. Soft powdery lime in Sanchore, Dhorimana and Chauhtan series increased with depth and internal drainage was read as excessive to well, depending upon topography and clays. Similar characteristics in soils of arid Rajasthan were also reported by Dhir and Kolarkar (1977) and Mahesh Kumar *et al.*, (2009).

Fine sand and loamy sand texture was dominantly observed on the surface and in the subsurface, respectively in Sanchore, Dhorimana and Chauhtan soil series. Fine sand characterized the dune complex series, while loamy sand textural classes were recorded below the surface in Sanchore and Dhorimana series (Table 1). Soils of Chitalwana series showed dominantly silty clay loam textural

Table 2. physical and chemical characteristics of soils of Narmada canal project of Rajasthan

Depth (cm)	Sand	Silt	Clay	WHC	$CaCO_3$	SOC	pH	EC	CEC*	P	K
	(%)						(1:2)			(kg ha^{-1})	
Sanchore series: Typic Torripsamments											
0-15	90.5	4.2	5.3	22.4	0.56	0.16	8.95	0.11	2.9	12.4	327
15-45	88.0	5.3	6.7	26.8	1.47	0.12	8.88	0.12	3.8	9.2	198
45-90	85.7	6.5	7.8	28.7	2.20	0.10	8.78	0.10	4.9	5.7	161
90-130	85.1	6.1	8.8	30.6	3.80	0.14	8.98	0.05	4.8	3.7	113
Dhorimana series: Typic Torripsamments											
0-20	91.6	3.4	5.0	21.8	0.55	0.11	8.78	0.09	1.9	10.1	278
20-60	90.2	4.3	5.5	25.2	1.5	0.10	8.67	0.15	3.5	7.7	186
60-120	88.7	5.0	6.3	27.0	3.8	0.08	8.76	0.25	4.6	4.1	113
120-160	88.8	5.2	6.0	26.7	4.4	0.08	8.74	0.25	4.6	4.1	101
Chauhtan series: Typic Torripsamments											
0-35	90.2	4.8	5.0	23.4	0.20	0.14	8.62	0.18	2.3	8.7	266
35-75	88.3	4.6	7.1	26.2	1.72	0.07	8.64	0.16	3.8	7.4	176
75-130	88.6	5.0	6.4	27.5	2.88	0.05	8.72	0.20	3.8	4.1	143
130-150	87.5	5.5	7.0	25.7	3.50	0.05	8.67	0.12	4.6	3.7	124
Chitalwana series: Typic Torrifluents											
0-20	50	26.3	23.7	49.8	9.0	0.42	8.95	0.65	20.8	34.0	578
20-40	48.7	30.0	21.3	48.4	7.0	0.38	8.88	0.61	21.5	23.7	281
40-65	56.7	25.7	17.6	32.0	1.1	0.27	8.86	0.54	18.8	13.4	258
65-105	80.6	8.9	10.5	26.8	0.40	0.12	8.72	0.46	7.7	11.7	203
105-150	82.4	9.8	7.8	27.5	0.30	0.14	8.80	0.61	8.4	9.5	169
Dune Complex series: Typic Torripsamments											
0-30	93.6	2.2	4.2	20.4	0.0	0.07	8.64	0.00	2.7	6.2	256
30-70	94.0	1.9	4.2	22.6	0.0	0.07	8.72	0.04	2.0	5.0	118
70-100	92.8	2.4	4.7	24.2	0.10	0.05	8.74	0.08	2.2	3.2	112
100-130	93.4	2.5	4.1	24.9	0.20	0.03	8.68	0.12	2.7	1.7	86
130-180	92.5	2.4	5.1	25.2	0.20	0.03	8.64	0.10	2.6	1.7	86

*cmol(P+) kg^{-1}

class at the surface and sandy loam, sometimes loamy sand in the sub-surface. Structurally soils were single-grained on the surface and had very fine to fine, weak sub-angular blocky structure in the subsurface of Sanchore and Dhorimana series. Structure development in these soils ran parallel to the clay content and textural class. Soil textural class and clay content also accounted for consistence in soils of Narmada canal command area of Rajasthan. Dry, moist and wet consistency was examined as loose, loose and none sticky and none plastic, respectively in Dune complex, Sanchore and Dhorimana series. A-C horizon sequence characterized in the identified soil series in the NCP area.

Soils of Dune complex series contained 85 to 96% sand, of which 81 to 91% was fine sand (Table 2). Clay and silt content varied from 2.6 to 5.1% and 1.5 to 2.8%, respectively. Water holding capacity (20 to 25%), organic carbon content (0.04 to 0.12%), available phosphorus (1.8 to 9.0 kg ha^{-1}) was low and potassium (287 to 84 kg ha^{-1}) was medium to low and occasionally high.

Sanchore and Dhorimana series contained relatively higher clay (4.0 to 11.0%) and silt (2.5 to 8.5%) than the dune complex series. These soils were mild to moderately alkaline (7.9 to 8.7), having 2.8 to 6.0 cmol (P^+) kg^{-1} cation exchange capacity; very low organic carbon (0.05-0.25%), low to medium available phosphorus (3.0 to 15.0 kg ha^{-1}) and medium to high potassium (135 to 350 kg ha^{-1}). Mean organic carbon (0.12%, 0.05 to 0.22%), the available phosphorus (3.5 to 14 kg ha^{-1}) and potassium (96 to 305 kg ha^{-1}) in Sanchore series were resembled to that of Dhorimana series (Table 2). Similar results were also reported earlier by Dhir and Kolarkar (1977); Mahesh Kumar *et al*. (2009); Chatterji and Joshi (1989) and Singh *et al*. (1995) while studying on soil resources characterization of arid Rajasthan.

Soils of Chitalwana series occupy the central part of the Narmada Canal Project and lie in the lower topographic position (locally known as Ned area) in deltaic region of Luni river, and have comparatively high water table in some parts of the year which require provisions of drainage and low intensity of irrigation water. These soils are stratified and have been deposited by river Luni and its tributaries. Therefore, these soils have the provision of low irrigation intensity (40%) and water allowances are also low (1.31cusec/100 acre) to overcome the problem of secondary salinization. Soils were moderately alkaline and were calcareous in nature. Clay and silt content ranged from 5.8 to 36 and 7.8 to 20.8, respectively in soil profiles of Chitalwana series. These have comparatively higher water holding capacity (28 to 47%) and cation exchange capacity [8 to 20 cmol (P^+) kg^{-1}]. Organic carbon (0.09 tp 0.51%) was low; available phosphorus (10 to 55 kg ha^{-1}) was mostly medium (high at few places) while potassium availability was marked as medium to high (170 to 818 kg ha^{-1}). These soils have comparatively higher water-holding capacity, organic carbon and available nutrients than the other soils of the Narmada canal command area (Chatterji and Joshi, 1989; Singh *et al*., 1995).

An excessive drainage and a high sand content (>90%) in Dune complex; comparable with Sanchore and Dhorimana (85 to 92%) soils series restricted pedogenesis. However, comparatively higher lime content of 8 to 12% in Ck horizons in Chitalwana series precluded the pedogenic process to move forward because of plasma immobilization (Rimmer and Greenland, 1976; Buol *et al.*, 1980) and massive soil structure was noted in the respective horizons.

Lime accumulations, mark of stratification, organic carbon distribution, sand, silt, clay content and structural development was marked as diagnostic characteristics for classifying the soils of Narmada canal command area of Rajasthan. Based on these all five identified soil series e.g. Dune complex, Sanchore, Dhorimana, Chauhtan and Chitalwana were classified in Entiosls soil order. Sand content >80% throughout the soil profile was the criteria to group soils of Sanchore, Dhoriman and Dune complex as Psamments, while irregular distribution of organic carbon and mark of stratification was the criteria for grouping Chitalwana series as Fluvents. Accounting aridic soil moisture regime as the differential characteristics at great group level, Psamments and Fluvents were classified as Torripsamments and Torrifluvents, respectively. Torripsamments and Torrifluvents represented the central concept of great group, consequently classified as Typic Torripsamments and Typic Torrifluvents at sub group. Typic Torrifluvents (Chitalwana soil series) were classified as the member of fine loamy, mixed hyperthermic family of their respective subgroup at family level. Classification Typic Torripsamments are not allowed below subgroup.

Dune complex series covered 7% of the total geographical area of Narmada Canal command area of Rajasthan. Sanchore Dhorimana and Chauhtan soils of aeolian plains were mapped on 38%, 32%, and 6% area of the Narmada canal command area, respectively (Fig. 2). The area under Chitalwana soil series was 10% of Narmada canal command area. Soil series of aeolian plain together was mapped on 83% area of NCP, alluvial soils were registered on 10% area of the Narmada Canal Project in Rajasthan.

Soil fertility: Soil fertility evaluation of an area or region is an important aspect in context of sustainable agricultural production, particularly for arid region where, sparse and highly variable precipitation, extreme variation in diurnal temperature, high evaporation and low humidity, the alluvial and aeolian landforms have given rise the variability in soils. However, due to the advent of NCP and the increase in population and its activities, many areas are being subjected to intensive cultivation, with even dunes several meters high being cultivated. Intensive agriculture, using irrigation water, fertilizers and pesticides, is known to cause changes in physical, chemical and biological properties of the soils (Lal, 1995), which require proper monitoring and

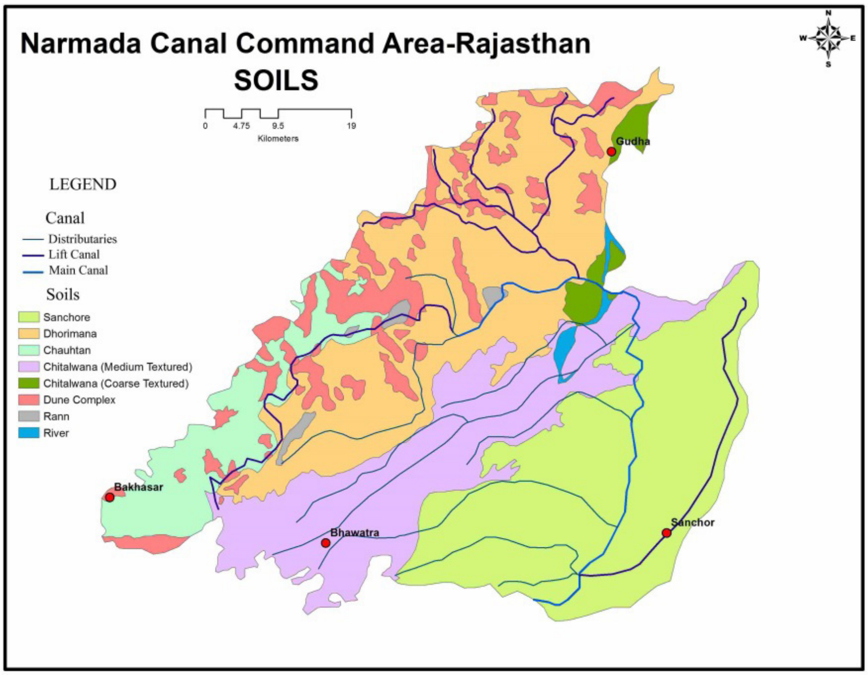

Fig. 2. Soil resources of Narmada canal project area, Rajasthan.

understanding for appropriate interventions to maintain land productivity. Therefore, in the present investigation, some important and relevant soil fertility parameters of the NCP area of Rajasthan have been studied and presented in Table 3. Soils of NCP, Rajasthan are generally alkaline in reaction and the pH values of soils varied from 7.62-9.98 with mean value of 8.70. The electrical conductivity (EC) of soils varied from 0.02 to 14.30 dS m^{-1} and most of the soil samples were found in normal range (<1.0 dS m^{-1}). The highest EC of 14.30 dS m^{-1} was recorded in alluvial soils in deltaic region of Luni River ephemeral stream carrying brackish water. Organic carbon (OC) content in these soils ranged between 0.03 to 0.42% with the mean of 0.14% (average of 200 samples). All the soil samples rated low in soil organic

Table 3. Soil physicochemical properties in Narmada Canal Project (NCP) area, Rajasthan

Soil Properties	Range	Mean	Standard deviation
Sand (%)	34.90-93.00	82.2	16.45
Silt (%)	2.50-26.50	7.14	7.04
Clay (%)	4.50-38.50	10.55	9.43
Bulk density (Mg m^{-3})	1.30-1.61	1.54	0.07
WHC (%)	17.50-39.80	23.08	5.53
CEC (c mol (p+) kg^{-1})	2.50-40.00	6.35	9.58
$CaCO_3$ (%)	0.02-12.5	3.05	3.02
pH	7.62-9.98	8.70	0.39
EC (dS m^{-1})	0.02-14.3	0.541	1.68
Organic Carbon (%)	0.03-0.42	0.14	0.07
Available N (kg ha^{-1})	61.91-191.00	102.25	27.23
Available P (kg ha^{-1})	1.41-47.84	10.38	8.62
Available K (kg ha^{-1})	56.25-652.50	178.26	107.91
DTPA extractable Fe (mg kg^{-1})	0.85-13.46	3.47	2.20
DTPA extractable Mn (mg kg^{-1})	1.72-14.55	5.26	2.44
DTPA extractable Zn (mg kg^{-1})	0.08-2.4	0.38	0.30
DTPA extractable Cu (mg kg^{-1})	0.02-1.38	0.34	0.25

carbon content. This also reflects poor available nitrogen status of soils. The OC content of soils was observed highest under irrigated crop lands and lowest in rainfed croplands. Higher amount of OC in irrigated croplands might be due to addition of crop residues in the soil. Variation in OC content may be due to high soil temperature and vegetative cover of soils in these land use categories. Earlier workers (Dhir, 1977; Gupta *et al*., 2000: Praveen-Kumar *et al.,* 2009; Mahesh Kumar *et al.,* 2021) also reported low OC content in soils of arid regions of India. Available nitrogen content in the soils ranged from 62-191 kg ha^{-1}, with mean value of 102 kg ha^{-1}, which indicates nitrogen deficiency in the NCP area of Rajasthan.

Available P content in soils showed wide variability with a range of 1.41-47.48 kg ha^{-1}. The situation is much better in the canal irrigated croplands, where the high values are especially measured in the alluvial soils in command areas of NCP. The higher amount of phosphorus in these soils inherited from the parent material from which the soils have been formed and also may be due to carry over effect of continuous application of phosphate fertilizers (Singh *et al.,* 2007; Mahesh Kumar *et al.,* 2021). Since these soil are cultivated in both rabi and kharif seasons with the support of canal water irrigation and receive more fertilizers (urea and DAP) and organic manures. The available K content in NCP area varied from 56.25 to 652.50 kg ha^{-1} with an average of 178.26 kg ha^{-1}.

The content of Fe, Mn, Zn and Cu varied from 0.85 to 13.46, 1.72 to 14.55, 0.08 to 2.40 and 0.02 to 1.38 mg kg^{-1} with the mean values of 3.47, 5.26, 0.38 and 0.34 mg kg^{-1}, respectively (Table 1). Overall, soils were found deficient in available Fe and Zn and adequate in available Mn and Cu in the Narmada canal command area across the land uses. Despite the localized natural endowment, Fe deficiency was found in most parts of the command area, which needs further attention. Considering the critical limits of 0.60 and 4.5 mg kg^{-1}, overall, Zn and Fe deficiencies were found over large parts of the command area, therefore, there is a need for Zn and Fe fertilization at recommended doses for rational crop yields. The results on Fe content are in close agreement with those reported by earlier workers (Joshi and Dhir, 1983; Gupta *et al.,* 2000) and they found that available Fe content was in the range of 3.0 to 20.00 mg kg^{-1}. Zn deficiency in arid soil has been reported from several other workers in arid and semi-arid areas of the country (Dhir, 1977; Praveen-Kumar *et al.,* 2009; Mahesh Kumar *et al.,* 2021). Given the critical limits for copper (0.20 mg kg^{-1}) soil has an adequate amount of available copper. Overall, the command area was well supplied with Mn contents and categorized as moderately high (Table 4). The results are in close agreement with Johari *et al*. (1978) and later with Gupta *et al.* (2000) and Mahesh Kumar *et al.* (2021) who reported that soils of arid Rajasthan well supplied with available Mn & Cu and it was present in the range of 0.70 to 45.90 mg kg^{-1} and 0.04 mg kg^{-1} to 4.86 mg kg^{-1}.

Geomorphic features, landform types and landuse pattern

The Narmada command area in Jalor and Barmer district covers the lower reach of Luni River where it forms a deltaic plain along the Rann of Kutchchh. Being a part of the Desert region of Rajasthan, along with flood plains, alluvial plains and saline ranns, there is extensive area under sand dunes. Based on interpretation of FCCs of IRS LISS-IV satellite images (Fig. 3) ten types of landforms have been identified and mapped (Fig. 3 and Table 4). Origin-wise, these landforms have been categorised under fluvial, aeolian and coastal types (Moharana *et al*., 2013). Among the landforms of fluvial origin, alluvial plains occur in maximum area (~37% area of total TGA of the command area) and have been further mapped as younger and older alluvial plain types. Younger alluvial plains occur on both sides of Luni River and form a part of flood plains. The older alluvial plains mainly in eastern part of command is a part of interfluvial zone between the main riverbed of Luni River and its tributaries joining the Luni from the eastern flank. Flood plains occurring in 17.8% area are located extensively on both sides of the Luni River and shows distinct fluvial morphology and drainage characteristics. It has been further subcategorised and delineated into younger and older types. At the confluence of Luni River with Rann, the width of younger flood plain is maximum (about 19.4 km). The width however reduces to 7 to 8 km near Isrol and Ranador villages in the middle reaches of river. The younger flood plains exhibit several smaller, isolated and

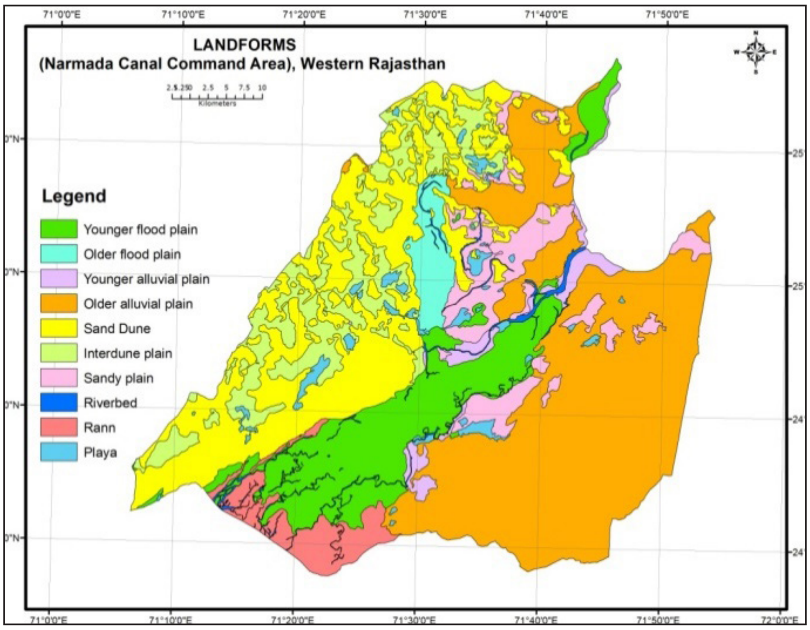

Fig. 3. Geomorphology and Landform map of Narmada Canal Project area, Rajasthan.

discontinuous narrow stream channels which are visible on FCCs of satellite images. The older flood plain forms the north-western part of younger flood plain and the land typically resembles a dry valley cutting through dune-interdune plains. Characteristically, this plain is similar to younger flood plain having similar drainage characteristics such as occurrence of discontinuous and narrow stream segments and many of them are buried by sand. These plains are wider (2.8 to 5.3 km) near Chimra and Agrawa and 2 to 3 km wide near Meethi village. To the west of this older flood plain is the area under extensive sandy uplands which are part of Barmer district, comprising several of 12 to 30 m high parabolic sand dunes and interdune plains occurring in 32% area. Such dune covered areas are mostly witnessed near Daboi, Meethi, Kaboli, Chalknechyaji, Gangapur and Bakhasar villages. Such dunes nearer to Rann areas in the south are of transverse types. In about 7% area is under scattered occurrence of sandy plains. Within the sandy undulating terrain, there are several inland saline depressions or playas which are remarkable features in the entire region. On the basis of their extent, they have been further categorised into smaller (0.2 to 0.6 km^2) and bigger types (3 to 9 km^2). Larger playas are located near Veriya and Doogri (in 9 km^2 area), Megawa (in 6 km^2 area) and south of Bherudi (in 3.5 km^2 area) are elongated and roughly round in shape. Between Bakhasar in the south and Pandawali in the north, saline depressions developed within the narrow interdune plains are linear shaped with a west to east alignment. One such saline depression at Veriya village is shallow and elongated (about 8 km long and 1.5 km wide) with a north-south alignment.

Table 4. Landforms of Narmada canal command area in Rajasthan

Landforms	Area (sq. km)	Area (%)
Younger Flood Plain	478.85	14.19
Older Flood plain	88.92	2.63
Younger alluvial plain	74.50	2.21
Older alluvial plain	1179.58	34.95
Sand dunes	722.55	21.41
Inter dune plains	349.81	10.36
Sandy plain	241.63	7.16
Rann	131.07	3.88
Playa	67.70	2.01
Riverbed	40.84	1.21
Total Command area	3375.45	100.00

Groundwater Characterization in NCP

The NCP area in Jalore and Barmer districts includes mainly three hydrogeological units: aeolian sands, younger alluvium and older alluvium. Tertiary formations are reported only from deep bore holes below depth of 140 m. About 14% of NCP area of Barmer and Jalore lies under younger alluvium with groundwater

Table 5. Descriptive statistics of groundwater quality parameters of Narmada Canal Project area Rajasthan

Quality parameter	Min	Max	Mean	SD	Variance	Skewness	Kurtosis
pH	7.22	9.10	8.12	0.47	0.22	0.34	-0.43
EC (dS m^{-1})	0.23	9.20	4.37	2.52	6.37	0.06	-1.03
Na^{+} (meq L^{-1})	0.27	95.50	35.99	21.54	464.13	0.41	0.12
[Ca^{2+}+Mg^{2+}] (meq L^{-1})	3.50	84.00	17.16	18.17	330.19	2.16	4.64
K^{+} (meqL^{-1})	0.00	1.38	0.33	0.34	0.12	1.85	3.14
Cl^{-} (meq L^{-1})	1.40	92.40	35.43	24.39	594.95	0.61	-0.56
CO_3^{2-} (meq L^{-1})	0.00	4.30	1.32	1.01	1.02	0.87	1.17
HCO_3^{2-} (meq L^{-1})	1.20	15.00	5.16	3.33	11.10	1.03	0.88
SO_4^{2-} (meq L^{-1})	0.00	26.10	4.35	4.88	23.80	2.91	10.98
SAR (mmol $L^{-1})^{1/2}$	0.15	36.13	13.91	8.04	64.71	0.74	0.83
RSC (meq L^{-1})	0.00	5.70	0.52	1.45	2.10	2.97	7.96

yield of 80 to 250 m^3 day^{-1} whereas 54% lies under older alluvium with groundwater yield of 60 to 200 m^3 day^{-1}. The remaining 32% area of the NCP in Barmer and Jalore lies in non-potential zone. Depth of groundwater in the deltaic region of Luni River was about 5 to 7 m below ground level (bgl). The area under groundwater depth of 10 to 20 m bgl has been increased from 77260 ha to 146368 ha whereas earlier area under 5 to 10 m depth was 132903 has which reduced to 44682 ha indicating wide spread withdrawal of water for irrigated agriculture. Introduction of Narmada canal in some areas has led to recharge of groundwater mainly due to seepage. Earlier the area under >40 m bgl depth was 8866 ha which was reduced to 936 ha indicating deep recharge of groundwater mainly due to canal. Rise of groundwater table by 0 to 3 m has been reported in 23% area (77797 ha) of NCP in Barmer district. However, slight depletion of groundwater by 0 to -1 m was also observed in 13.56% area (45701 ha) of Barmer district. Decline of groundwater table by 0 to -3 m was observed in 14% area of NCP in Jalore district whereas deep decline of groundwater by -3 to -7 m was also observed in 1% area.

The groundwater samples were collected along the distributaries/lifts and minors, which were further analysed to determine different quality parameters following standard procedure. The result revealed that the pH of groundwater samples varied from 7.22 to 9.10 (neutral to strongly alkaline) with a mean value of 8.12 (Table 5), which indicated that in the study area water resources were moderately alkaline in nature. The higher pH of the groundwater samples (pH > 8.5 nearly 41%) may be due to high concentrations of Na^{+}, Ca^{+2}, Mg^{+2}, and concentration (Rao *et al.*, 1982; Al-Tabbal and Al-Z boon, 2012) as and are hydroxyl generating ions (Bhat *et al.*, 2018). Among water-soluble anions Cl^{-} and varied from 1.40 to 92.40 me L^{-1} and 0.00 to 26.10 me L^{-1}, respectively. Among the cations Na^{+} is the dominant cation whose concentration ranged from 0.27 to 95.50 me L^{-1}. The concentration of other cations viz., Ca^{+2} + Mg^{+2} and K^{+} in groundwater samples varied from 3.50 to 84.0 and 0.0 to 1.38 me L^{-1} with the mean value of 17.16 and 0.33 me L^{-1} (Table 5). In groundwater samples, the order of cationic abundance (in me L^{-1}) is Na^{+}> Ca^{+2}+Mg^{+2} >K^{+}. The high concentrations of Na^{+} may be attributed to a base-exchange reaction and leaching of sodium salts with the movement of water through sediments and also by the dissolution of rock salts and weathering of Na rich minerals (Etteieb *et al.*, 2017 and Kumar *et al.*, 2009). The low levels of K^{+} in groundwater samples may be ascribed to its tendency to be fixed by clay minerals and to participate in the formation of secondary minerals (Matthess, 1982; Jalali, 2005).

The concentration of anions viz., Cl^{-}, , and in groundwater samples varied from 1.40 to 92.40, 0 to 4.30, 1.20 to 15.00 and 0.0 to 26.10 me L^{-1} with mean of 35.43, 1.32, 5.16 and 4.35 me L^{-1} (Table 6). In groundwater samples, concerning anionic chemistry, the order of anionic abundance (in me L^{-1}) is Cl^{-}>>>. The higher chloride content in the groundwater may be due to natural processes like weathering, dissolution of salt deposits and irrigation drainage return flow (Kumar *et al.*, 2009). Also, the source of chloride may be non-lithological in nature (poor sanitary conditions, irrigation-return-flows, chemical fertilizers, etc.). Sulphate content in groundwater might be due to the presence of sulphide-bearing minerals and gypsum in aquifer materials and by the application of sulphate-rich fertilizers and industrial wastes (Sridharan and Nathan, 2017). Moreover, the application of soil amendments like gypsum is expected to be responsible for higher content in the groundwater. The dominance of bicarbonate ions indicates a mineral dissolution process. The higher concentration of bicarbonate may be ascribed to the reaction of carbonate minerals with carbon dioxide gas (CO_2) and the dissolution of CO_2 from the possible mechanisms (Houatmia *et al.,* 2016).

Sodium absorption ratio (SAR): The sodium adsorption ratio is the most useful parameter for determining the suitability of groundwater for irrigation. The SAR of soil solution increases as the SAR of irrigation water increases, increasing the soil's exchangeable sodium (Bhat *et al.*, 2018). The SAR values helped to classify groundwater as S1: excellent/low (<10), S2: good/medium (10-18), S3: fair/high (18-26) and S4: poor/very high (>26) as suggested by Richards (1954). According to this classification, SAR values ranged from 0.15 to 36.31 with a mean value of 13.91 and ranges from low sodicity class S1 to very high sodicity S4 class (Table 6). However, the mean value of SAR was 13.91, which fell into the medium sodicity class (S2). About 29% of samples belonged to the excellent group (S1 class) i.e. very low sodicity and can be used safely for irrigation purposes, and 40% of samples grouped under the S2 class i.e. good/medium sodicity class. While, 19% of samples (8 nos) lied under the S3 class i.e. high sodicity class and 12% of samples were of the very high sodicity class, which indicated that the development of sodicity might arise in the soil if these waters are taken for irrigation purposes. High SAR values (>10) could cause sodium to replace adsorbed calcium or magnesium, thereby damaging the soil structure. When the concentration of Na^+ is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg^{+2} and Ca^{+2} ions. The exchange process of sodium in water for magnesium and calcium in soil reduces permeability and eventually results in soil with poor drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Collins and Jenkins, 1996; Saleh *et al.,* 1999).

Residual Sodium Carbonate (RSC): RSC values of groundwater ranged from nil to 5.7 me L^{-1} with a mean value of 1.1 me L^{-1} (Table 1). Richards (1954) classified that water with RSC > 2.5 meq L^{-1} are unsuitable for irrigation, while those with 1.25-2.50 meq L^{-1} are medium and <1.25 meq L^{-1} are presumably safe. Continuous use of water having RSC >2.5 meq L^{-1} leads to salt build-up which may hinder the air and water movement by clogging the soil pores and lead to degradation of the physical condition of the soil. This RSC pattern clearly indicates the occurrence of alkaline water causes the low permeability of the soil. Water with high RSC has high pH and land irrigated by such water becomes infertile owing to the deposition of sodium carbonate (Eaton, 1950). Based on the classification, RSC data revealed that most of groundwater samples categorized as permissible/safe group, however, at few locations groundwater contains more than the desired level.

Salinity point of view, EC of groundwater ranged from 0.23 to 9.20 dS m^{-1} (low to very high salinity) with a mean value 4.37 dS m^{-1} (high to very high salinity), which falls under salinity class C2 and C5 i.e. high salinity indicating unsuitability for irrigation. The variation in EC may be ascribed to anthropogenic activities and geochemical processes existing in this region. Based on the classification, SAR and RSC data revealed that most of groundwater samples categorized as permissible/safe group, however, at few locations groundwater contains more than the desired level.). Continuous irrigation with such waters gradually soils will be more saline than before, and more problematic and degraded. The inherent soil salinity of the canal command area was due to its location in the Luni river basin, which is a salty river basin. In few pocketed patches, problem of soil salinity was also observed, however, this was either due to seepage of water from canal or due to use of shallow saline groundwater for irrigation. Thus, Such problem of soil salinity /secondary salinization in arid zone can be avoided by adoption of such pipeline network-based micro irrigation system (drip and sprinklers and by repair and maintenance of canal/ lining materials in canal on regular basis or by judicious use of water in agricultural field.

Conclusion

Benchmark sites in NCP area, Rajasthan were identified and characterized in order to assess the state of natural resources in response to continuous irrigation. Five soil series e.g. Sanchore, Dhorimanna, Chohtan, Dune complex and Chitalwana in the NCP, Rajasthan have been characterized and mapped. Analysis of soils of the NCP area of Rajasthan showed that the soils are generally mildly to strongly alkaline in reaction, poor in organic carbon content. The content of P is low to medium whereas, high values are especially obtained in the alluvial soils in command areas of Chitalwana soil series. Available K content is largely medium to high in the NCP area. Among the micronutrients Zn and Fe are low to marginal in large areas, whereas, Cu and Mn are found adequate. Interpretation of FCCs of IRS LISS-IV satellite images revealed ten types of landforms in the NCP area, which have been further categorised under fluvial, aeolian and coastal types as per its origin. Among the landforms of fluvial origin, alluvial plains occur in maximum area (~37%) of the NCP area and have been further mapped as younger and older alluvial plain types, which mainly occurs at both sides of Luni river and the interfluvial zone between the main riverbed of Luni and its tributaries. About 14% of NCP area of Barmer and Jalore lies under younger alluvium with groundwater yield of 80-250 m^3 day^{-1} whereas 54% lies under older alluvium with groundwater yield of 60-200 $m^3 day^{-1}$. Analysis of groundwater samples from the NCP area revealed that the groundwater resources were moderately alkaline in nature, cationic abundance of the groundwater was $Na^+ > Ca^{+2}+Mg^{+2} > K^+$, anionic abundance of the groundwater was Cl^->>> and majority of water samples grouped under the S2 class i.e. good/medium sodicity class. The majority of groundwater samples were in high to very high salinity class (C4 and C5) i.e. unsafe for irrigation due to high salinity. These benchmark characterization of soil, landform and groundwater resources of the NCP area in Rajasthan may be quite useful in future assessments on the impact of canal irrigation in arid landscapes.

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